DIELECTRIC CONSTANT MEASUREMENT OF MATERIALS BY A MICROWAVE TECHNIQUE: Application to the Characterization of Vegetation Leaves

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Overview

Abstract

A New microwave method has been proposed for modeling the plant leaves in the wave-guide is presented. In our model, we introduce a model based on the geometrical structure of vegetation leaves, water inside leaves is generally distributed between different tissues in not well known proportions. To understand and predict its dielectric distribution behavior, it is necessary to involve its morphology, this leaf is parallel venation one with a midrib more developed than the minor veins. The physical phenomenon of diffraction occurs when a wave meets this type of structure. For this, we used the Generalized Equivalent Circuit Method (GECM). This dynamic method takes into account most of the involved physical phenomena.

Abstract

Calculating the permittivity of the material to be characterized from the measured reflection coefficient constitutes inverse problem. The complexity of the electromagnetic analysis does not allow to find an analytical relation between these two parameters. We have developed a computer code based on the Genetic Algorithm, to numerically solve the inverse problem. To validate this program, we performed measurements on standard materials of known permittivity. The method is verified with measurement of Teflon (PTFE), FR4 (Flame Resistant 4) and Pure Acetone.

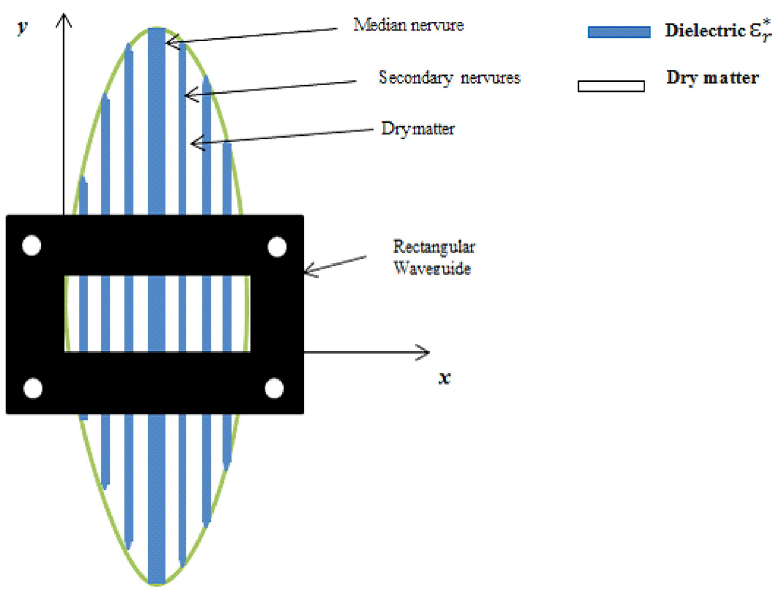
Keywords: Corn leaves, wave-guide, dielectric properties, microwave, genetic algorithm.

Biography

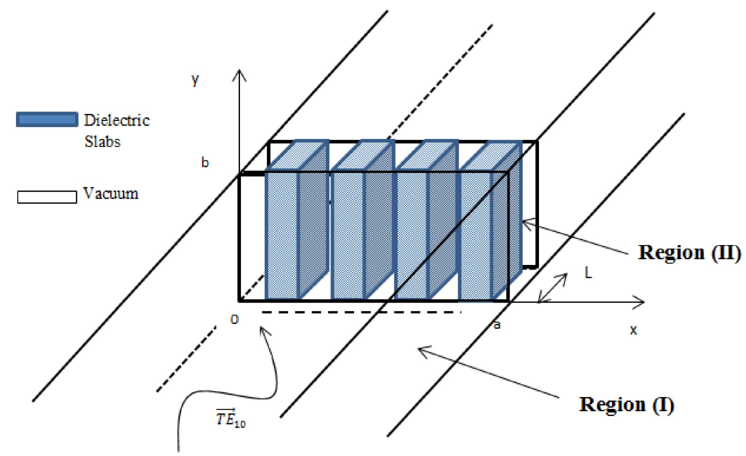
Houssemeddine KRRAOUI was born in Tunisia, in 1986.
He received Bachelor's degree in Electronics from Bizerte Faculty of sciences (FSB),Tunis, and the M.Sc. and Ph.D. degrees in Telecommunication from National School of Tunisia (ENIT).
He is currently an researcher with the Sys'Com Laboratory, National Engineering School of Tunis (ENIT). His current research interests simulation and modeling of the circuits and systems radio frequency for the communication and the teledetection microwave.

Theoretical Background

The structure studied Fig.1.b is reduced to the domain composed of two regions: (region I empty guide and region II guide loaded with multi-dielectric).



(a)



(b)

Fig – (a) Corn leaf, (b) Illustration of the problem: Permittivity determination of thin materials inside rectangular waveguides.

Theoretical Background

Due to the symmetry structure with regard to the discontinuity surface, only half of the generalized equivalent circuit (GEC) is needed, the simplified GEC is depicted in Fig.2.

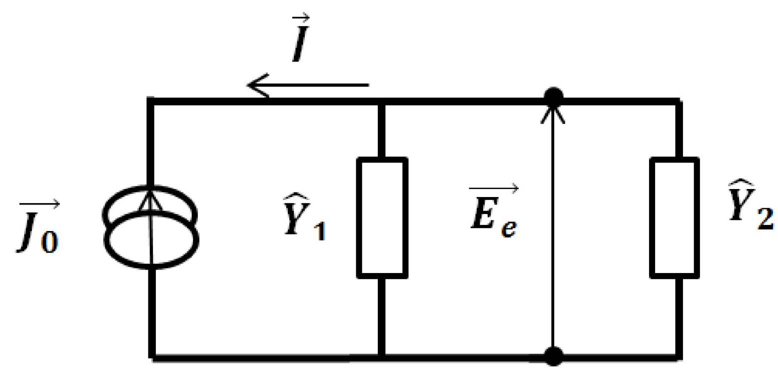


Fig – Equivalent circuit of the half-structure.

Let $\left(f_{mn}\right)_{m,n\in 1,2,\ldots MN}$ be the local modal basis of the wave-guide with electric walls.
The excitation sources are $J_0 = I_0.f_0$ where f_0 represents the active mode and I_0 the amplitude.

Theoretical Background

The problems unknown E_e is expressed as a series of known test functions g_p weighted by unknown coefficients v_e expressed as follow:

$$E_e(x, y) = \sum_{pq} v_e . g_{pq}(x, y) \tag{1}$$

where

$$g_{pq}(x, y) = f_{mn}(x, y) \tag{2}$$

The generalized Ohm and Kirchhoff laws applied to the GEC depicted Fig.2 lead to the equations system (3).

$$\begin{cases} J_0 = -J & (12.a) \\ J = (\hat{Y}_1 + \hat{Y}_2).E_e & (12.b) \end{cases} \tag{3}$$

Theoretical Background

This system is written then in the following matrix form:

$$[J_0] = -[(\hat{Y}_1 + \hat{Y}_2)][E_e] \tag{4}$$

Next, we apply the Galerkin method to the equations system (3): Equation (4) are projected on the trial functions g_p Therefore, the system (4) is rewritten as in (5).

$$\begin{pmatrix} I_0 \\ 0 \\ \vdots \\ 0 \end{pmatrix} = \left(\ \langle g_q, (\hat{Y}_1 + \hat{Y}_2) | g_p \rangle \ \right) \begin{pmatrix} V_0 \\ v_1 \\ \vdots \\ v_P \end{pmatrix} \tag{5}$$

Theoretical Background

This matrix equation (5) can be written in a simplified manner as follows:

$$\begin{pmatrix} I_0 \\ [0] \end{pmatrix} = - \begin{pmatrix} A_{11} & [V_{11}] \\ [V_{22}] & [B] \end{pmatrix} \begin{pmatrix} V_0 \\ [v_e] \end{pmatrix} \tag{6}$$

From the relation (5), one deduces the system from the equations below:

$$\begin{cases} I_0 = -[A_{11}][V_0] - [V_{11}][v_e] \\ [0] = -[V_{22}][V_0] - [B][v_e] \end{cases} \tag{7}$$

The resolution of this system will allow us to calculate the matrix admittance defined by:

$$[Y] = \begin{pmatrix} \dfrac{Y_{even} + Y_{odd}}{2} & \dfrac{Y_{even} - Y_{odd}}{2} \\ \dfrac{Y_{even} - Y_{even}}{2} & \dfrac{Y_{even} + Y_{even}}{2} \end{pmatrix} \tag{8}$$

Theoretical Background

From which one can deduce the scattering matrix of the structure:

$$[S] = \left(-[Y]/Y^{TE10} + \bar{\bar{I}} \right) . \left([Y]/Y^{TE10} + \bar{\bar{I}} \right)^{-1} \tag{9}$$

Where $\bar{\bar{I}}$ the identity matrix and

$$Y^{TE10} = \frac{\sqrt{\left(\frac{\pi}{a}\right)^2 - k_0^2}}{j\omega\mu_0} \tag{10}$$

Extraction of the relative permittivity (Inverse problem)

The complex permittivity ε_r^* of the material can not be analytically expressed. However, the electromagnetic analysis requires a problem inverse combined with a numerical optimization procedure.
This procedure consists, by considering progressive adjustment of the complex permittivity ε_r^*, to converge the theoretical reflection coefficient S_{11}^{thoric} that calculated using the generalized equivalent circuit method (GECM), to the measured reflection coefficient by using the network analyzer (VNA) S_{11}^{mes}.
The iterative approach consists, for each frequency point, to solve the system of equations in two unknowns given by the following relationship:

$$F(\varepsilon_r^*) = S_{11}^{theoric}(\varepsilon_r^*) - S_{11}^{mes} \tag{11}$$

Measurement set-up

An Agilent HP 8510C vector network analyzer (VNA) was used to measure the magnitude and phase of reflection coefficient S_{11} of dielectric slabs placed in a wave-guide. Two coax-to-wave-guide adapters are used to connect an empty wave-guide section to Port 1 and the sample holder to Port 2 of the VNA. The measurement system is shown in Fig.3.

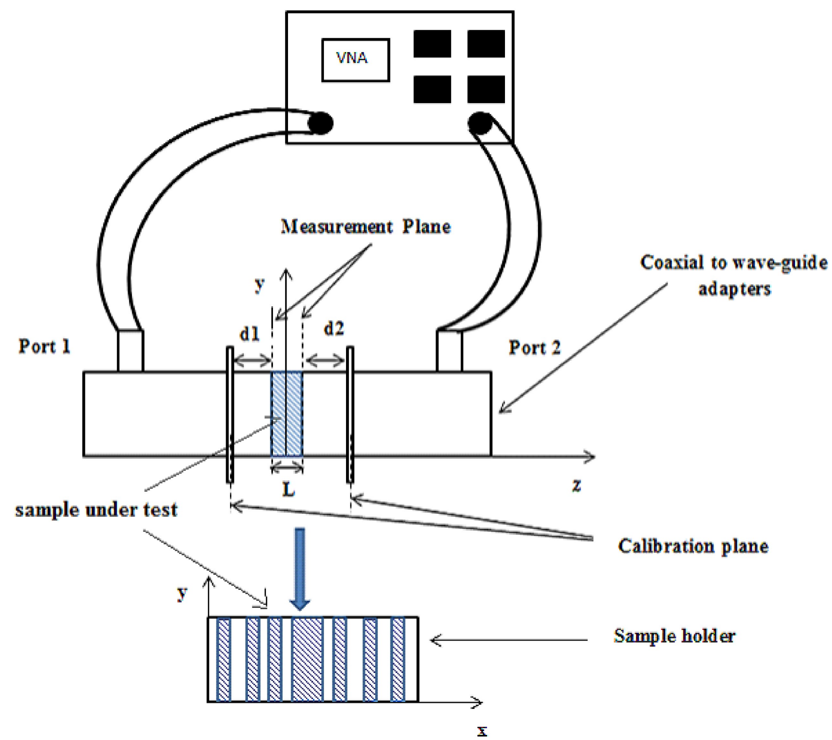


Fig – Measurement set-up.

Numerical model validation

A computer MATLAB code based on the Moment method combined with GEC was developed and we had applied it to the analysis of the following structure:

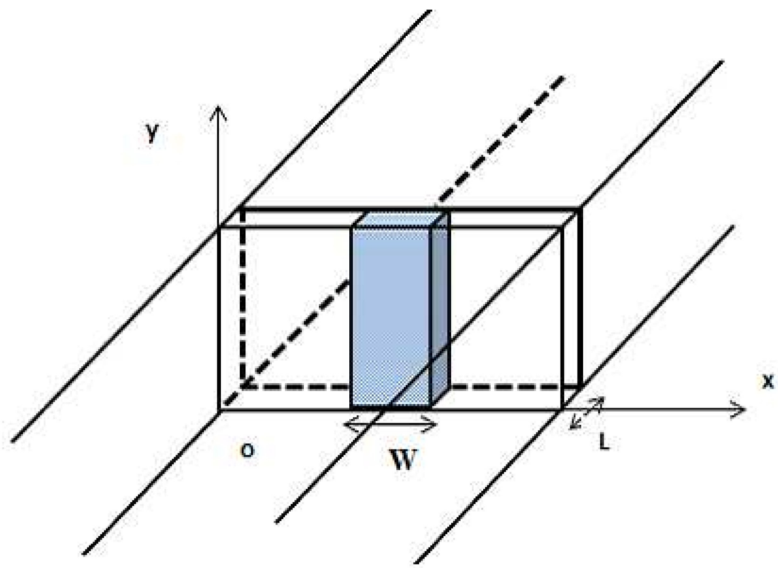


Fig – Dielectric obstacle in empty waveguide (a = 22.86, b = 10.16) dielectric: width:(w) , thickness:(L)

Numerical model validation

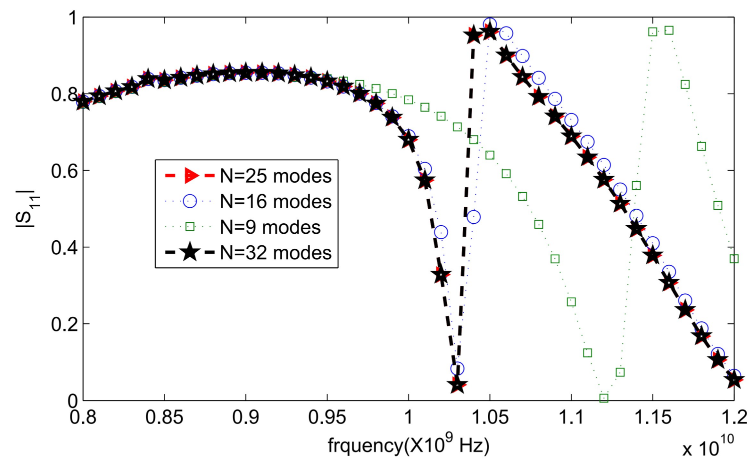


Fig – Convergence curve of reflection coefficient number of modes: dielectric: width: w = 0.525.a, $\varepsilon_r = 8.2$, thickness: L = 0.3937.a

Numerical model validation

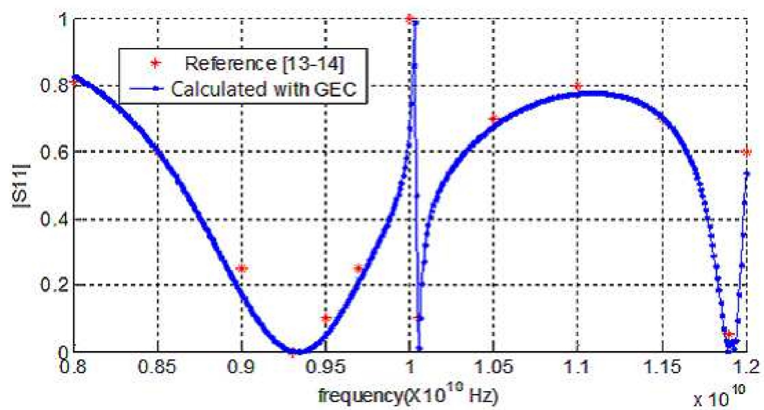


Fig – Reflection coefficient of a one dielectric obstacle in empty waveguide (a = 22.86, b = 10.16): dielectric: width: w = 0.525.a, $\varepsilon_r = 8.2 - j.0.006$, thickness: L = 0.5249.a

Validation of measurement techniques

The plot in Fig.7.a shows the best and mean values of the population in every generation and Fig.7.b plots the vector entries of the individual with the best fitness function value in each generation.

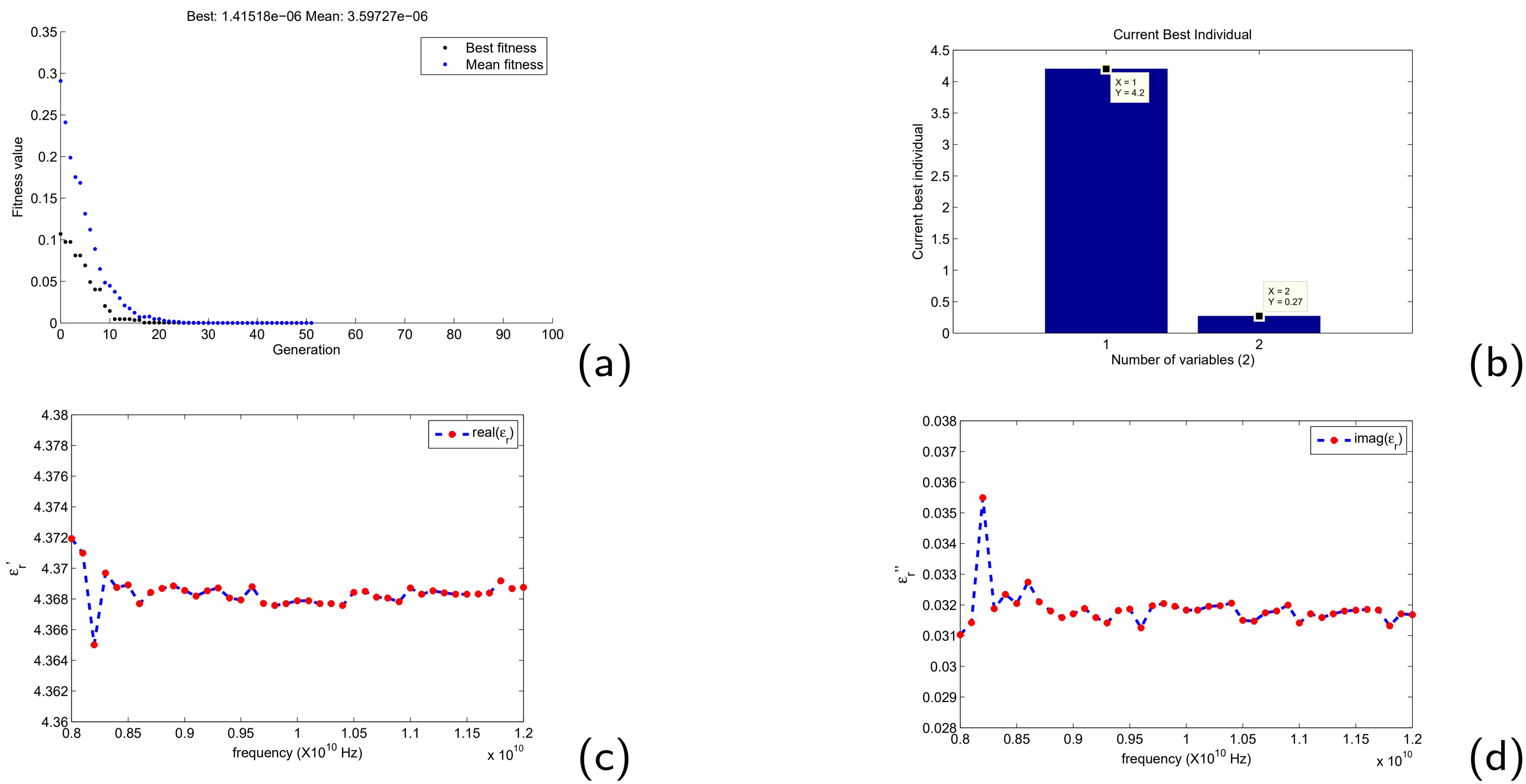
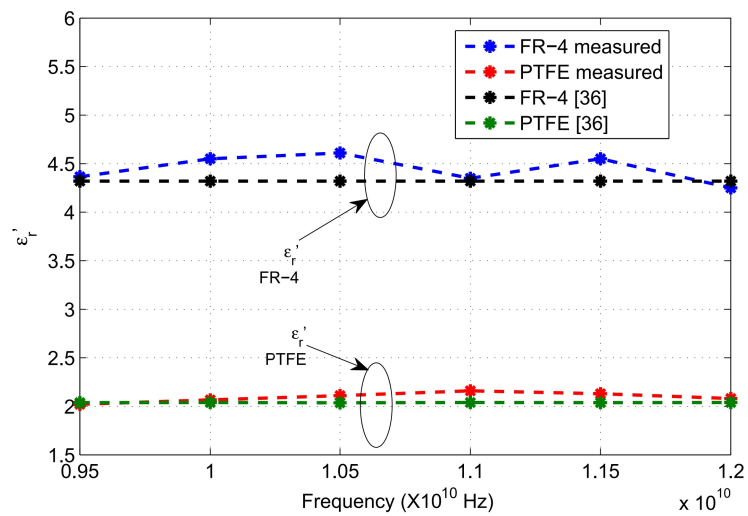
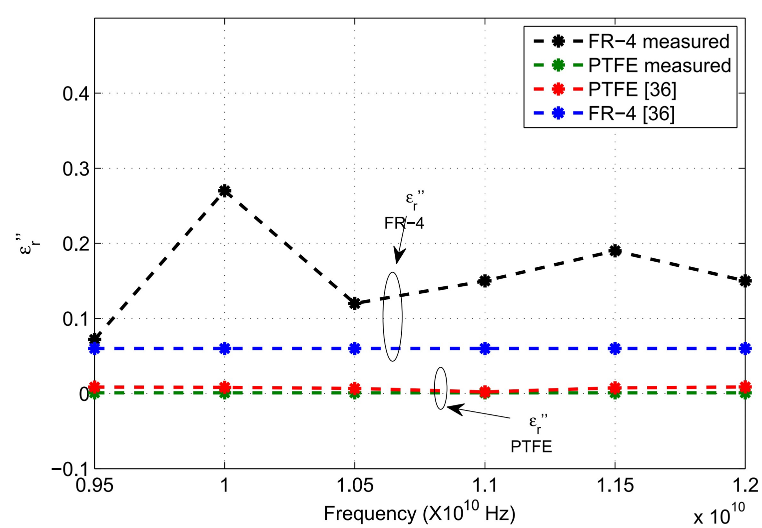


Fig – (a) Best and mean values of the population in every generation, (b) Best individual at F=10GHz, (c) Measured dielectric constant real part and (d) imaginary part of 1.5-mm thick FR-4 (Flame Resistant 4) Dielectric width ($w \simeq a$).

Validation of measurement techniques



(a)



(b)

Fig – Measured complex dielectric constant, of 1.5-mm thick FR-4. Dielectric width ($w = 11.4mm < a$) and polytetrafluoroethylene (PTFE) samples, dielectric width ($w = 10.16mm < a$), $\varepsilon_r^* = 2.008 - 0.00076i$, $L = 22.86mm$. (a) real part, (b) imaginary part

Extraction of the relative permittivity characterizing the veins of the corn leaves

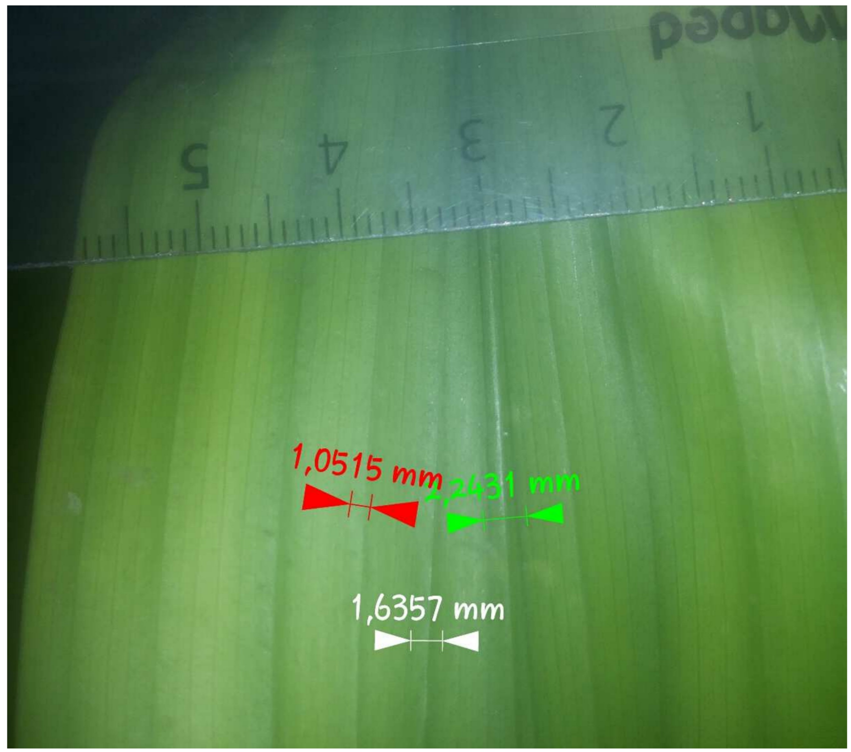
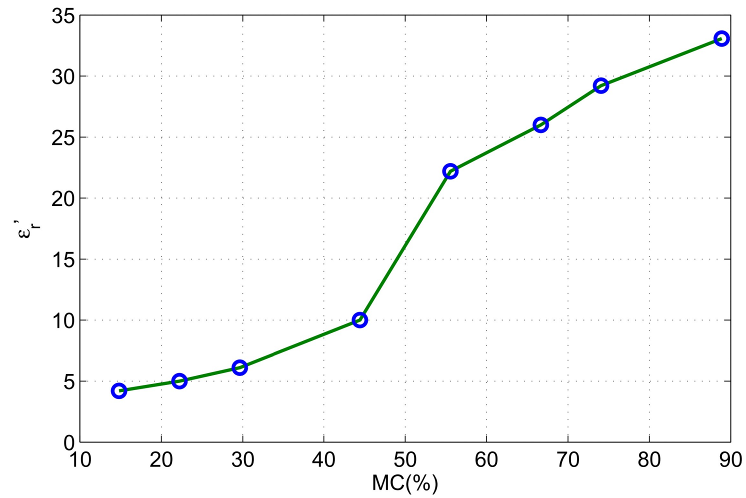
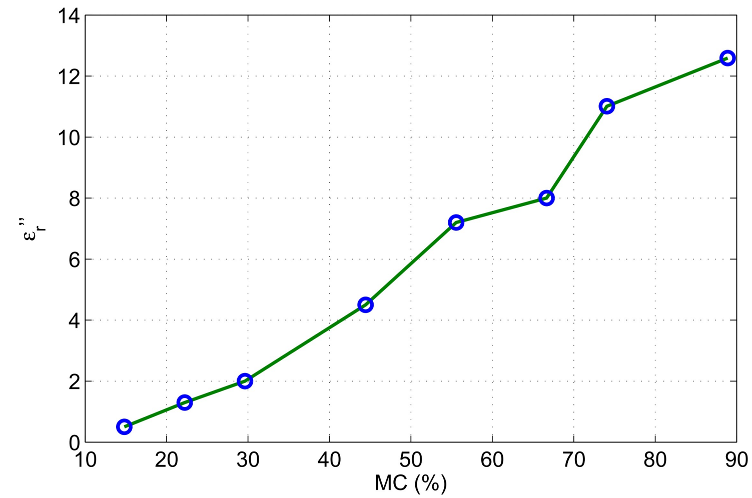


Fig – Photo of Corn leaf. Dimensions measurement is made with an android application called (photo ruler), which have an accuracies of ($\pm 0.001 mm$).

MC Dependence



(a)



(b)

Fig – Moisture content (MC) as function of measured dielectric constant of the mediane nervure and secondary nervures at $T = 22^{\circ}C$ and Frequency=10GHz

Polynomials interpolation (12), (13) are obtained from the calibrated curve Fig10.

$$MC(\%) = (5.51e^{-7}).(\varepsilon_r')^7 + (-6.7e^{-5}).(\varepsilon_r')^6 + (3.3e^{-3}).(\varepsilon_r')^5 + (-8.7e^{-2}).(\varepsilon_r')^4 + (1.2).(\varepsilon_r')^3 + (-1.1e^{+1}).(\varepsilon_r')^2 + (5.7e^{+1}).(\varepsilon_r')^1 + (-1.02e^{+2}) \quad (12)$$

MC Dependence

$$MC(\%) = (5.12e^{-4}).(\varepsilon_r'')^7 + (-1.89e^{-2}).(\varepsilon_r'')^6 + (2.57e^{-1}).(\varepsilon_r'')^5 + (-1.57).(\varepsilon_r'')^4 + (4.19).(\varepsilon_r'')^3 + (-4.17).(\varepsilon_r'')^2 + (1.03e^{+1}).(\varepsilon_r'')^1 + (1.02e^{+1}) \quad (13)$$

This polynomial function allows immediately to obtain the humidity of any other sample by measuring ε_r^* at $Frequency = 10GHz$ at $22^\circ C$.

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